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ORIGINAL PAPER

Composition, structure and diversity characterization of dry tropical forest of Chhattisgarh using satellite data

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Abstract: The purpose of this study was to characterize the land use, vegetation structure, and diversity in the Barnowpara Sanctuary, Raipur district, Chhattisgarh, India through the use of satellite remote sensing and GIS. Land cover and vegetation were spatially analyzed by digitally classifying IRS 1D LISS III satellite data using a maximum likelihood algorithm. Later, the variations in structure and diversity in different forest types and classes were quantified by adopting quadratic sampling procedures. Nine land-cover types were delineated: teak forest, dense mixed forest, degraded mixed forest, Sal mixed forest, open mixed forest, young teak plantation, grasslands, agriculture, habitation, and water bodies. The classification accuracy for different land-use classes ranged from 71.23% to 100%. The highest accuracy was observed in water bodies and grassland, followed by habitation and agriculture, teak forest, degraded mixed forest, and dense mixed forest. The accuracy was lower in open mixed forest, and sal mixed forest. Results revealed that density of different forest types varied from 324 to 733 trees ha^{-1}, basal area from 8.13 to 28.87 $m^2 \cdot ha^{-1}$ and number of species from 20 to 40. Similarly, the diversity ranged from 1.36 to 2.98, concentration of dominance from 0.06 to 0.49, species richness from 3.88 to 6.86, and beta diversity from 1.29 to 2.21. The sal mixed forest type recorded the highest basal area, diversity was highest in the dense mixed forest, and the teak forest recorded maximum density, which was poor in degraded mixed forests. The study also showed that Normalized Difference Vegetation Index (NDVI) was strongly correlated to with the Shannon Index and species richness.

Keywords: forest, Shannon Index, species richness, RS and GIS, land use, NDVI

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Introduction

Proper planning, management, and monitoring of the natural resources depend on the availability of accurate land use information. Over the years, remote sensing has been used for land use and land cover mapping in different part of the India (Gautam and Narayan 1983; Sharma et al. 1984; Jain 1992; Rathore 1996; Palaniyandi and Nagarathinam, 1997; Jaiswal et. al. 1999; Chaurasia and Sharma 1999).

Life-supporting systems on planet earth are facing alarming threats due to rapid declining of diversity and complexity of living organisms (Stoms and Estes 1993). Chhattisgarh state—covered with more than 44% of the geographical area under tropical forests—has strong potential for carbon sequestration. However, increased anthropogenic activities have led to degradation of virgin forests in last few decades. According to the recent report published by Forest Survey of India (FSI) on state of forests of India, there is a net loss of 189 km^2 of forests occurred between 2005 and 2011 in Chhattisgarh. Further a fairly good amount (3.5 -5%) of dense forests are converted into open and degraded forests during this period.

Remote sensing and GIS techniques are now seen as efficient and powerful tools for characterization of land use and vegetation in the tropics (Roy and Ravan 1996; Swamy 1998; Turner et al. 2003; Jha et al. 2005). Remote-sensing data provide reliable and unbiased information on different land use features, their spatial extent, and also dynamic properties. GIS techniques complement remote sensing by way of spatially integrating different satellite-derived thematic maps with ancillary data through overlay procedures (Tucker et al. 1985; Sudhakar et al. 1999).

The amount, rate, and intensity of land use and land cover are very high in the dry tropical forest ecosystems of Chhattisgarh, India. There is a dire need to evolve sustainable land use practices for conserving diversity, enhancing productivity, carbon sequestration and improving biogeochemical cycles. The present study was conducted to analyze the land use, vegetation structure, diversity of a dry tropical forest ecosystem. Satellite remote sensing

and GIS techniques were used for the characterisation of land use, structure, and diversity.

Materials and methods

Study area

This study was carried out in a watershed representing a dry tropical forest ecosystem in part of Barnowpara Sanctuary, Raipur Forest Division, Chhattisgarh, India during 2004–2007. The Wildlife Sanctuary was established in 1976 under Wildlife Protection Act of 1972, covering an area of 245 km^2. About 76% of the study area/watershed falls in the sanctuary. The watershed comprises an area of 165.64 km^2, of which different forests cover more than 70% area. It is situated between 21°20' to 21° 28' north latitudes and 82° 21' to 82°26' east longitudes. The climate is dry, humid, and tropical and consists three major seasons: rainy, winter, and summer. The mean annual rainfall of the study area ranges from 1200–1350 mm. The mean annual temperature of the study area is about 26.5 °C, which begins to increase in March to May. The highest temperature goes beyond 41.8 °C in May and lowest below 12.7 °C in December. The soils of the study area are quite variable in their physical and chemical properties and fall three classes, *Inceptisols, Alfisols* and *Vertisols* (Soil Survey Staff 1960). The geographical location of study area is depicted in Fig. 1.

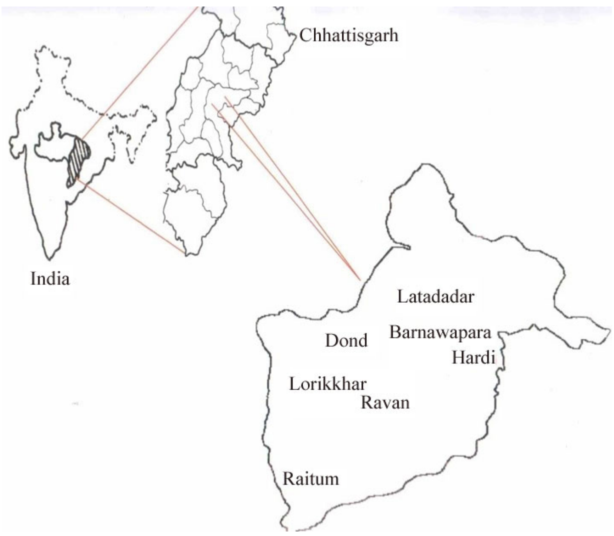

Fig. 1: Layout map of the Barnowpara Sanctuary, Raipur Forest Division, C.G.

Materials

IRS ID LISS III cloud-free digital data was procured from the NRSA Data Centre in Hyderabad, India. The data covers the entire study area of Barnowpara and its surrounding environs. Digital analysis was performed on ERDAS Imagine (Version 8.6) Image analysis software and the ancillary data collected from SOI topographical maps was analyzed in ARC-GIS (Version 8.2). The base map was drawn from a survey of India topographical 64 K/7 and 64 K/11 on 1:50,000 scale and used for geometric rectification of satellite data. A reconnaissance survey was made to recognize important vegetation types in different physiographic units and related to the tonal variations on the satellite image for accurate classification.

Pre-processing of satellite data

Geometric distortions were removed by geo-referencing the image-to-map registration using Survey of India sheets on 1:50,000 scale. The image registration was performed using the nearest neighbourhood resampling algorithm with the first-order polynomial. Scenes were geometrically corrected after selection of proper ground control points with a root-mean-square (RMS) error of less than half pixel.

Classification of satellite images

Digital classification of land use, land cover, and vegetation was done using the maximum likelihood algorithm. Nine land cover/vegetation classes were found: teak forest, sal mixed forest, dense mixed forest, open mixed forest, degraded mixed forest, young teak plantation, open grass lands, agriculture and habitation, and water bodies. Supervised classification was carried out using ERDAS IMAGINE/ENVI software. The maximum likelihood classifier (MLC) was used for determining land use and vegetation types. It is based on the estimated Gaussian probability density function for each of the reference classes by the following expression:

$$P(X_k|\,^{\mathrm{i}}) = \frac{1}{(2x)n/2\,|V_i|^{1/2}} \exp[-i/2(X_k - \mu_i)^T V_{\mathrm{i}}^{-1}(X_k - \mu_i)$$

where $P(X_k|^i)$ = Probability of pixel X_k being a member of class I; n = Number of wave bands; X_k = Vector for i^{th} pixel in all wave bands; μ_i = Mean vector for class i over all wave bands; V_i = Variance-covariance matrix for class i; $|V_i|$ = i^{th} order determinant; and $(X_k\text{-}\mu_i)^T\ V_i^{-1}(X_k\text{-}\mu_i)$ = Mahalanobis distance between the pixel and centroid class i in feature space.Therefore, to categorize the measurement vector X of an unknown pixel in to a specific class, the maximum likelihood decision rule was applied to compute the value of $P(X_k|^i)$ for each class.

Generation of vegetation indices

Vegetation indices are mathematical transformations designed to assess the spectral contribution of vegetation to multispectral observations. The most widely used green vegetation indices are formed with data from discrete red and near-infrared (NIR) bands. These vegetation indices operate by contrasting intense chlorophyll pigment absorptions in the red wavelength against the high reflectivity of plant materials in the NIR wavelength. The indices derived from satellite data were used draw the relationships between structural variables, diversity indexes of different vegetation types. Important vegetation indices derived

from the satellite data are presented in Table 1.

Table 1: Important vegetation indices derived from the satellite dat

S. No.	Vegetation Indices	Formulae
1	Ratio Vegetation Index (RVI)	NIR/RED (Band 3/Band 2)
2	Perpendicular Vegetation Index (PVI)	$\sqrt{(R_{soil} - R_{veg}) + (IR_{soil} - IR_{veg})}$
3	Normalized Difference Vegetation Index (NDVI)	(NIR – R)/(NIR+R), (Band3-Band 2/ Band 3 + B and 2)
4	Soil Adjusted Vegetation Index (SAVI)	((NIR – RED)/(NIR + RED) + L (1 + L))
5	Transformed Vegetation Index (TVI)	$(ND + 0.5)^{½}$
6	Advances Vegetation Index (AVI)	$(NIR \times (256 - R) \times (NIR - R)^{1/3}$

Diversity analysis

Species diversity parameters for tree layer, shrub layer, and herbaceous components were determined using basal cover values. Plant diversity in different forest types was quantified by the following diversity indices:

(a) Shannon index (Shannon and Weaver, 1963) was used for species diversity

$$H' = -pi \log 2\ pi$$

where, *pi* is the proportion of total stand basal area represented by the i^{th} species

(b) Concentration of dominance was measured by the Simpson index (Simpson, 1949)

$$Cd = (Ni / N)^2$$

where Ni and N were the same as explained above and it varies between 0-1.

(c)Equitability (e) was calculated as suggested by Pielou (1969)

$$e = -H' / \ln S$$

where H’ = Shannon index and S = the number of species

(d)Species richness was calculated by the following Margaleaf (1958) equation

$$d = S - 1 / \ln N$$

where S = total number of species; N = basal cover of all species (m^2 ha^{-1}).

(e) Beta diversity was calculated as (Whittaker, 1972)

$$bd = Sc / s$$

where *Sc* = total number of species in all sites and s is average species per site.

Relationship between NDVI and species diversity

The relationship between NDVI and Shannon index was developed. The best model was selected on the basis of regression coefficient (r^2) and t- values. This model was used for computation of species diversity in different vegetation types of study area.

Results

Land cover and vegetation mapping

The spatial extent of different categories of land cover along with their classification accuracies is presented in Table 2, and land cover classes were delineated by classifying the satellite data using the maximum likelihood algorithm (Classified Image in Fig. 2). Among the different land cover types, open mixed forest occupied the largest area, while the lowest area was covered by water bodies. Open mixed forest occupied 20.98% of total area of the watershed followed by dense mixed forest in 19.12 percent, habitation and agriculture in 16.84% and degraded mixed forest in 13.92% of total area. Open grasslands were only found in 1.58 percent area. The classification accuracy for different land use classes ranged from 71.2–100%. The highest accuracy was observed in water bodies and grassland followed by habitation and agriculture, teak forest, degraded mixed forest and dense mixed forest. The accuracy was poor in open mixed forest and sal mixed forest.

Table 2: Spatial extent of vegetation types in Barnowpara sanctuary, Raipur Forest Division, Chhattisgarh

S. No.	Vegetation category	Area (ha)	Accuracy (%)
1	Teak Forest	2257.4	83.3
2	Dense Mixed Forest	3167.8	75.5
3	Open Mixed Forest	3476.7	73.3
4	Degraded Mixed Forest	2305.4	76.5
5	Grassland	261.8	100.0
6	Sal Mixed Forest	971.4	71.2
7	Young Teak Plantation	1333.2	87.2
8	Habitation & Agriculture	2790.1	98.7
9	Water body	12.1	100.0
	Total	**16563.8**	

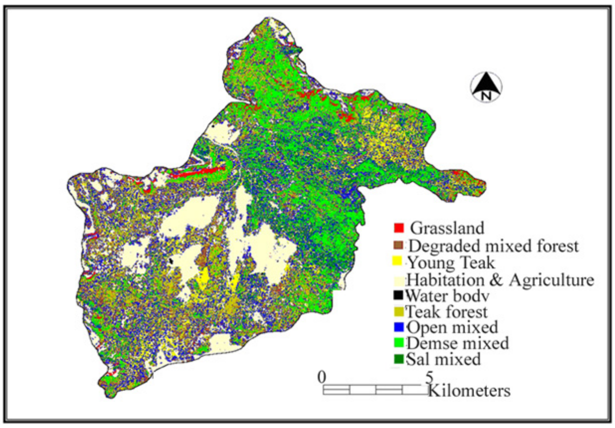

Fig 2: Classified image of Barnawapara Sanctuary, Raipur Forest Division (CG)

Structure & diversity analysis of different forest types

Results on diversity (number of trees present per ha) and basal area (cross-sectional area of stem per ha) distribution of major forest types are presented in Fig. 3a-3b. Density varied from 324 to 733 stems ha^{-1}. It was highest in teak forest followed by dense mixed forest, open mixed forest, sal mixed forest and lowest in degraded mixed forest (Fig. 3a). Basal area ranged from 8.13 to 28.78 m^2 ha^{-1} in different forest types. Sal mixed forest recorded the highest basal area followed by dense mixed forest and teak forest. The lowest basal area was found in degraded mixed forest (Fig. 3b). Further, structure attributes—like density, basal area, average height, and number of species—varied significantly from plot to plot and also to the region, which can be clearly depicted from figures.

The various diversity indices—Shannon index (H'), Simpson's index (cd), species richness (d), equitability (e) and beta diversity (bd)—were computed for different forest types to see the variations in plant diversity. Attempts were also made to compute the parameters of the diversity of each forest type in different layers (trees, shrubs and herbs). The results on diversity of vegetation in different forest types are summarized in Table 3.

Shannon index values in the different forest types varied from 1.420 to 2.980 in trees, from 0.840 to 3.050 in shrub and from 1.680 to 2.650 in herb layers. Simpson index values ranged from 0.070 to 0.490 in the tree category, 0.052 to 0.620 in the shrub and 0.170 to 0.330 in herb vegetation of different forest types. The species richness values in the tree layer varied from 3.880 to 6.860, in the shrub from 0.190 to 3.490, and in the herbs from 0 to 0.001 (Fig. 3c). Beta diversity in all the vegetation varied from 1.130 to 5.000.

Correlation and regression relationships between vegetation indices, structural and diversity parameters

Correlation analysis was performed between vegetation indices and structural parameters of dry tropical forests including the Shannon Index and results are presented in Table 4. It is evident from the results that the NDVI was positively correlated with LAI, density, basal area, and Shannon index; there was a negative correlation between different vegetation indices, except NDVI. (Figs. 4 and 5). Among the parameters studied—Shannon index, LAI, density, and basal area—were strongly correlated with NDVI and highly significant at both the 1 and 5 percent levels, as compared to other vegetation indices. NDVI was best fitted based on higher r^2 values for all the structural and diversity parameters in the dry tropical forest of Chhattisgarh (Table 4).

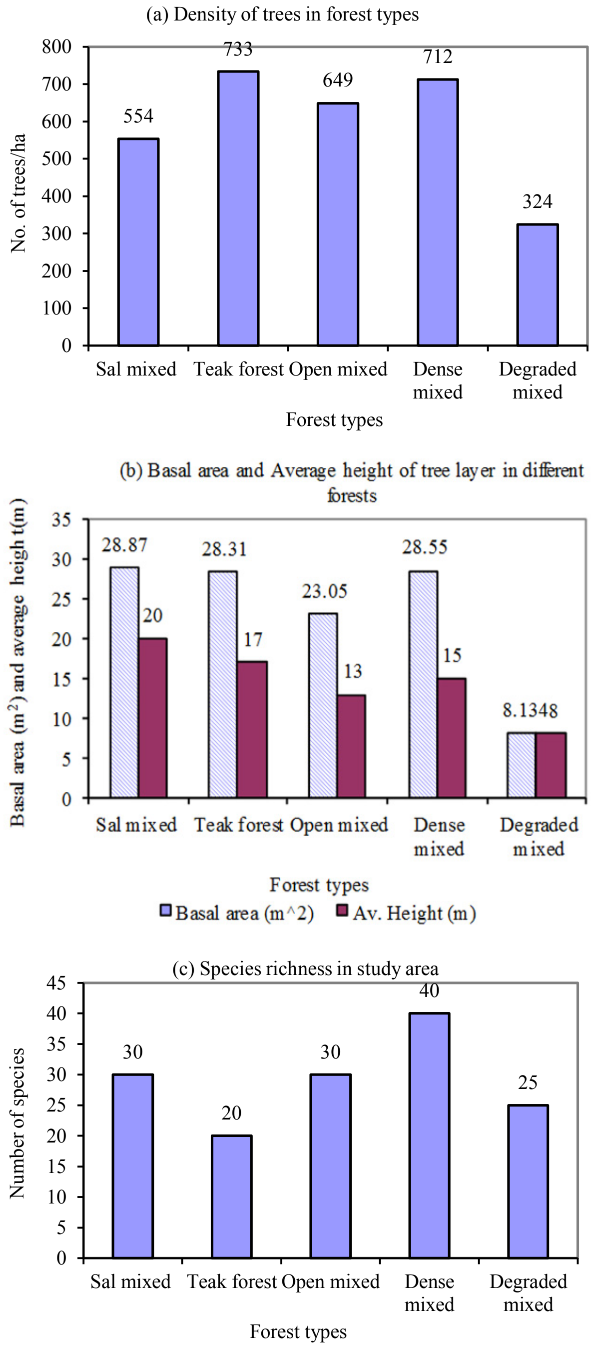

Fig. 3: Density (a), Basal area (b) and Species richness (c) of dry tropical forests, C.G.

Table 3: Diversity parameters for Trees, Shrubs and Herbaceous layer of different forest types of Chhattisgarh, India

Forest type		Shannon Index	Simpson Index	Species Richness	Equitability	Beta diversity
Tree Layer	Teak Forest	1.360	0.490	3.880	0.510	2.210
	Sal Mixed Forest	2.140	0.260	6.550	0.680	1.350
	Open Mixed Forest	2.550	0.140	6.370	0.840	1.470
	Dense Mixed Forest	2.980	0.060	6.860	0.940	1.290
	Degraded Mixed Forest	1.420	0.070	6.200	0.540	2.210
Shrub Layer	Teak Forest	0.840	0.390	0.190	0.022	2.000
	Sal Mixed Forest	2.634	0.077	0.320	0.972	1.710
	Open Mixed Forest	0.998	0.629	2.720	0.378	1.860
	Dense Mixed Forest	3.047	0.052	3.490	0.972	1.130
	Degraded Mixed Forest	2.527	0.095	1.100	0.957	1.730
Herbaceous Layer	Teak Forest	1.860	0.295	-	1.340	4.000
	Sal Mixed Forest	1.880	0.290	-	1.360	2.350
	Open Mixed Forest	1.680	0.330	-	1.220	2.220
	Dense Mixed Forest	2.650	0.170	0.001	1.360	3.500
	Degraded Mixed Forest	2.350	0.213	0.001	1.310	5.000

Table 4: Correlations among important vegetation indices and structural parameters in dry tropical forest of Chhattisgarh

	NDVI	AVI	PVI	TVI	SAVI	RVI	LAI	Density	Basal area	Shannon Index
NDVI	1	0.73**	0.67**	0.49*	0.50*	0.49*	0.86**	0.65**	0.82**	0.44*
AVI		1	0.93**	0.28 NS	0.22 NS	0.37 NS	0.76**	0.24 NS	0.57**	0.15 NS
PVI			1	0.20 NS	0.23 NS	0.23 NS	0.69**	0.25 NS	0.58**	0.12 NS
TVI				1	0.60**	0.72**	0.42*	0.11 NS	0.34 NS	0.24 NS
SAVI					1	0.57**	0.35 NS	0.39 NS	0.53**	0.39 NS
RVI						1	0.45*	0.24 NS	0.48*	0.30 NS
LAI							1	0.54**	0.72**	0.098 NS
Density								1	0.82**	0.33 NS
Basal area									1	0.49*
Shannon index										1

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed); NS. Non-significant.

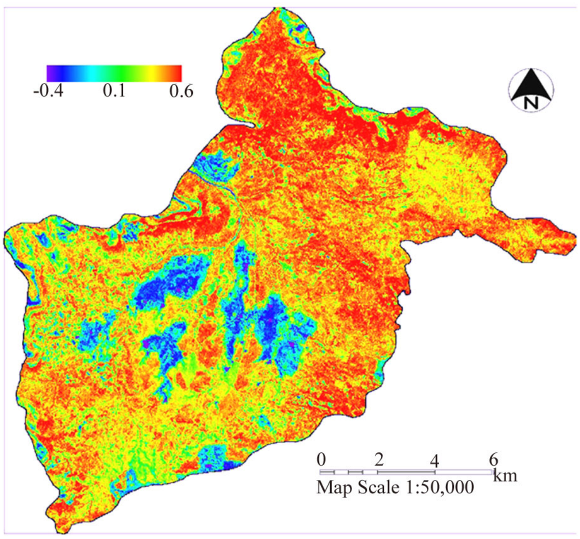

Fig. 4: NDVI map of Barnowpara sanctuary, Raipur Forest Division, CG

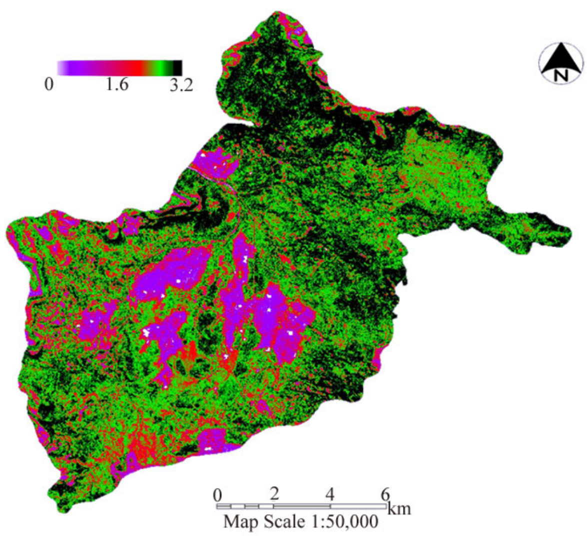

Fig. 5: Species diversity map of Barnowpara sanctuary, Raipur Forest Division, Chhattisgarh

Discussion

Land cover and vegetation mapping

The earlier studies also demonstrated the use of remote-sensing satellite data in a number of classification schemes for characterizing land-use types (Townshend et al. 1987; Saxena et al. 1992; Kushwaha and Oesten 1993; Tuomisto et al. 1994; Sudhakar et al. 1994 and Singh et al. 2005). All these studies concluded that maximum likelihood classification was a useful technique suitable for different environments.

The present study also shows that higher classification accuracies were achieved for certain vegetation classes like teak forest, degraded forest, open mixed forest, grassland, habitation, and water bodies. This may be ascribed to distinct spectral behavior of these forest types, making them easily separable, which helped in achieving better accuracies compared to other classes. However, the sal mixed forest and dense mixed forest classes showed lower accuracies because the pixels of these classes were intermixed with each other. They were also not spectrally as homogenous as other classes like teak forest, open mixed forest and degraded mixed forests.

The use of only single-date satellite data in the present study also limited the classification accuracy. Ravan et al. (1996) evaluated the accuracy of vegetation classification of dry deciduous forests of Madhav National Park, M.P. India through digital and visual interpretation of Landsat TM data. The use of temporal data showed higher classification accuracy (67.07%) compared to single-date satellite data. The effectiveness of multitemporal data for improving the level of classification and accuracy was also reported by Ravan et al. (1996), Sehgal and Dubey (1997), Jayakumar et al. (2000), Joshi et al. (2004) and Pandey et al. 2006.

Structure and diversity of tropical forests

The present study reveals that density, basal area, and LAI are positively and strongly correlated to NDVI in comparison to other vegetation indices. This is due to fact that the amount of NIR reflection, linearly increases with the increase in vegetation density, height, and number of canopy layers until it attains saturation level at about 8 layers beyond which there is no further increase in reflection. Several earlier researchers showed a close relationship between vegetation amount (structure) and NIR and NDVI in different forest environments (Franklin 1986; Spanner et al. 1990; Cohen and Spies 1992; Jakubauskas and Price 1997).

Satellite-remote sensing and GIS techniques have emerged as potential tools for characterization of vegetation structure and diversity. Using a combination of spectral features and ground information on diversity, distribution, and dominance of various species, it is possible to generate spatial databases on components of species richness and diversity (Nath et al. 2005).

The diversity parameters of these forests are comparable with the diversity indices reported in different tropical forests (Singh and Singh 1991; Prasad and Pandey 1992; Ravan 1994; Varghese and Menon, 1998 and Singh et al. 2005). Singh and Singh (1991) reported the Shannon- Wiener index values ranged from 1.9 to 2.8, concentration of dominance from 0.18 to 0.75, species richness from 0.21 to 0.93, and beta diversity was 3.1 for mixed dry deciduous forests of U.P. India. Similar trends are found in Prasad and Pandey (1992) in sal mixed forest and teak forests of Madhya Pradesh.

The lower diversity of dry tropical ecosystems in this study is attributed to the fact that a large proportion of resources is shared by only few species (< 27), while in tropical evergreen forests, a greater number of species (>75) efficiently shared the resources and higher diversity was found in those forests (Pascal 1992; Swamy 1998). It is also evident from the results that Shannon index values are higher than Simpson Index values for different forest types. An inverse relationship was found between the Shannon and Simpson Indexes. These results were in agreement with earlier findings of Singh and Singh (1991), Swamy (1998) and Singh et al. (2005).

Conclusions

Our study shows that satellite remote-sensing and GIS techniques are reliable tools for the characterisation of land use, vegetation structure, and diversity of the dry tropical ecosystems of Chhattisgarh, India. It also demonstrates that it is possible to achieve desirable classification accuracy (71.23 to 100%) for different land-cover classes in dry tropical ecosystems using the maximum likelihood algorithm even with single-date satellite data. The use of multi-date satellite data will improve the classification accuracy and also more precisely delineate the sal mixed forests. The use of high-resolution (<1 m) panchromatic and multi-temporal satellite data could have made it possible to further classifying Sal mixed and dense mixed forest into the précised types like Sal (Shorea) -Terminalia, Mixed forests with Bamboo brakes, however the use of IRS-ID LISS III data in this study with a spatial resolution over 20 m restricted in delineating these types.

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